Customized Orthopaedic EVA Footwear to deal with Foot Deformities: An Innovative Approach

Synopsis

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In

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Motivation

Foot deformities can either present at birth or develop over some time. The definition of foot deformities is not predicted generally. The proposed solutions are surgical or non-surgical method to cure the foot deformities. Custom made shoes are high in prices which are not affordable to the masses. Here an attempt is made to prepare custom made shoe last and shoe using EVA at nominal price so that everyone can afford the orthopaedic shoes according to the type of foot deformity.

1. Introduction

Foot problems are generally seen on daily basis. It may be developed at early stage or over some time due to various factors like ill-fitting shoe, genetically problem, pointed shoe, arthritis etc. Care must be given to feet because approximately 25% of total bones present in human feet [1]. In general, two methods are likely to be suggested to cure the foot deformities i.e., surgical method and non-surgical method. Here low-cost customized method is used for making solid block shoe last [2] which is prepared from single stroke manufacturing technique with POP and some waste plastic materials. Once shoe last is prepared, it is followed towards the EVA press molding to make the custom-made orthopaedic shoe for various foot deformities. [3-4]

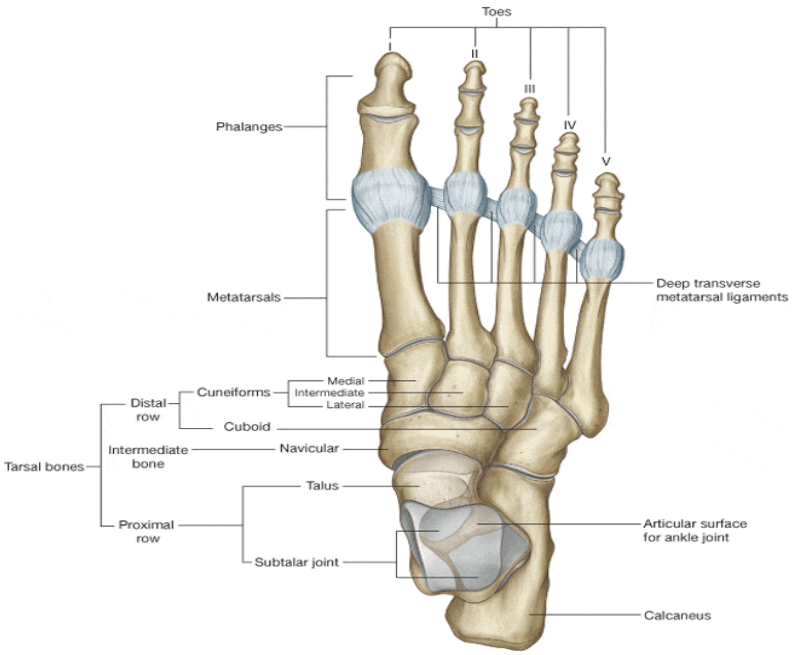

Fig. 1 Structure of foot

(Source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.mortonsneuroma.com%2Fblog%2Fcontributing-factors-leading-mortons-neuroma%2F&psig=AOvVaw3maMB6K1ircH0IPeXWiFCu&ust=1693062997200000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCIjq76aN-IADFQAAAAAdAAAAABAn)

2. Literature review

Ellen Sobel talked about the weight-bearing foot pressures which were found to be lower when walking in a shoe as compare to barefoot. Adding a soft cushioned in the shoe which further decreases the weight-bearing pressure. [5]

Asad Ayub said that the initial treatment is primarily conservative and must first address the patient's footwear. Foot padding, taping, night splints, foot exercises, orthotic devices, nonsteroidal anti-inflammatory medications, or a combination of these treatment modalities may be prescribed. Allowance should be made for adequate space in the shoe to prevent further injury. Orthotic devices may provide short-term symptomatic pain relief for mild to moderate Bunion deformity. [6]

J. Leng proposed a system using MATLAB and foot scanner to obtain a data to fit customer foot shape custom made shoe last by preserving the fashion factor against the original last. [7]

Shuping Xiong started the concept to deliver the custom made last at the given address. Firstly, the various parameters can be selected in last and laser scan the foot in the next stage. Then CAD file is prepared according to measurement and prepared the final last using CNC machine and ready for shoe production. [8]

Nibedita Rout proposed a model to make custom shoe last using foot scanning and CAD/CAM system to prepare shoe last. Collection of data is must followed by 3D visualization and rest work is done by CNC machine to make custom made shoe last. [9]

Salvatore Moscadini fabricated a soft leather shoe with a wide toe box and preferably a soft sole for relief of symptoms of flat foot and Bunion. Different orthotic devices like bunion pads, night splints, bunion posts etc. may also help in relieving symptoms. No assurance that orthotic devices prevent progression of the deformity and it is uncomfortable for a patient because it occupies space within the toe box. According to Kilmartin et al (1991) found that the Bunion angle increased more in patients who used orthotics and concluded that orthoses did not prevent progression of a Bunion deformity. [10]

A. Luximon applied a non-medicated hammertoe pad for hammertoe deformity. It will decrease pressure on that area. Wearing a shoe with a deep toe box, if the hammertoe becomes inflamed and painful. Apply some ice packs generally to reduce pain. It is important to remember that this treatment will make the hammertoe feel better but it does not cure the condition. Too tight or narrow shoes should be avoided.

[11]

Hylton B. Menz talked about all the orthoses were of full length and modified by adding a cut-out section beneath the first metatarsal and trimming the distal edge to the level the second to fifth phalanges. This shoe is characterized by a rounded sole in the anteroposterior direction and a soft cushioned heel with radius of curvature of the MBT shoe is 33 cm overall, 18 cm at the forefoot, 43 cm at the midfoot, and 11 cm at the heel. [12]

J Peixoto talked about the method using 3d scanning to scan foot and pass on all the information to the 3D printing machine for making custom made insole. Once insole is ready according to the deformity, the custom made footwear can easily be made. [13]

Chakma Shimul talked about how to make custom made shoe last for a deformed person using CAD file and CNC. Once the custom made shoe last is ready, the customized footwear can be made. [14]

Mike Frecklington applied an extra-depth in the forefoot region to accommodate fore foot deformity. Soft leather upper and smooth lining offered protection, laces, padded heel counter to improve the fit at the heel side and a long inside counter was given to improve rearfoot stability and for supporting arches. Footwear characteristics included a wide and deep toe box used to accommodate for the foot orthoses. [15]

Paulus Wisnu Anggoro prepared a custom made orthotic insole using CAD file and CNC machine for patients suffering from diabetes. He used materials like wood and PVC for making shoe last. [16]

Nor Rofizah Johari prepared a custom made shoe for different patients by raising the insole platform so that the whole construction can be made on last according to the deformities. [17]

Chul Hyun Park applied treatment for patients who favour footwears with a lower heel and a wider toe box section. An MT bar on the sole of footwear reduces pressure loading on the space between MT heads and transfers it more proximally. This MT pad is generally made of rubber, polyurethane, or silicone. This pad reduced the pressure under painful MT heads by spreading it to a larger area, improving the functional ability. [18]

Md. Imrul Kayes Limon used a concept of POP and mold to made the custom made shoe last from deformed person foot. Once your last is ready after finishing, it is used to make footwear using natural and synthetic materials according to the type of deformity. [19]

Ermakova E.O. proposed a concept of automated measuring the inner dimensions of a deformed person foot and to develop an algorithm using the data. This integrated approach helped to make the custom made orthopaedic footwear in a better way. [20]

Liliia Chertenko prepared the customized shoe last using scanning, CNC machine and additive manufacturing technique. It also makes the insole so that custom made last can easily be made. [21]

Haddaya Umar conducted a survey on 101 people who were suffering from plantar fasciitis. It was also planned to investigate the impact of daily wear footwear on foot health by mentioning the various features of the shoes worn daily by the sufferer. Data collected by using non-probability convenient sampling technique. [22]

Liliia Chertenko prepared the customized shoe last by using scanning, CAD file and CNC machine. It also shows the various sections in last by which your last is prepared. [23]

3. Human foot Anatomy

Foot anatomy is the science of knowing the structure of the feet and interrelation of its parts. The human foot is consisted of bones, muscles, Ligaments, & tendons which are covered by the skin. The whole system can support the body while it is standing, walking, and running. [24]

3.1 Function of Feet

Feet have the following two functions:

a) Supporting the weight of the body & to balance in an erect position i.e., stability

b) Propelling the body forward i.e., flexibility

3.2 Introduction of Bones

The skeleton of the body gives strength, supports its weight, and protects the more vulnerable organs. It is formed by long and short bones. Long bones are responsible for its movement and the short bones are associated with the weight bearing of the foot. There are total 26 bones present in human foot. [11]

3.3 Distribution of Bones

It is divided into three parts-

a) Tarsus –back portion of the skeleton of the human foot is termed as tarsus. It has seven irregular shape bones. The body weight is transferred through heel bone to the ground.

b) Metatarsus - consists of five metatarsus (long bones). The first three joins with three cuneiform and next two with the cuboids.

c) Phalanges- the phalanges are the fourteen long bones forming the toes. It is divided into three sub groups as [1, 11]-

- Proximal phalanges (5- bones)
- Middle phalanges (4-bones)
- Distal phalanges (5-bones)

Table 1 Distribution of Bones

Group	Number of Bones	Types of Bones
Tarsus	7	Short
Metatarsus	5	Long
Phalanges	14	Long

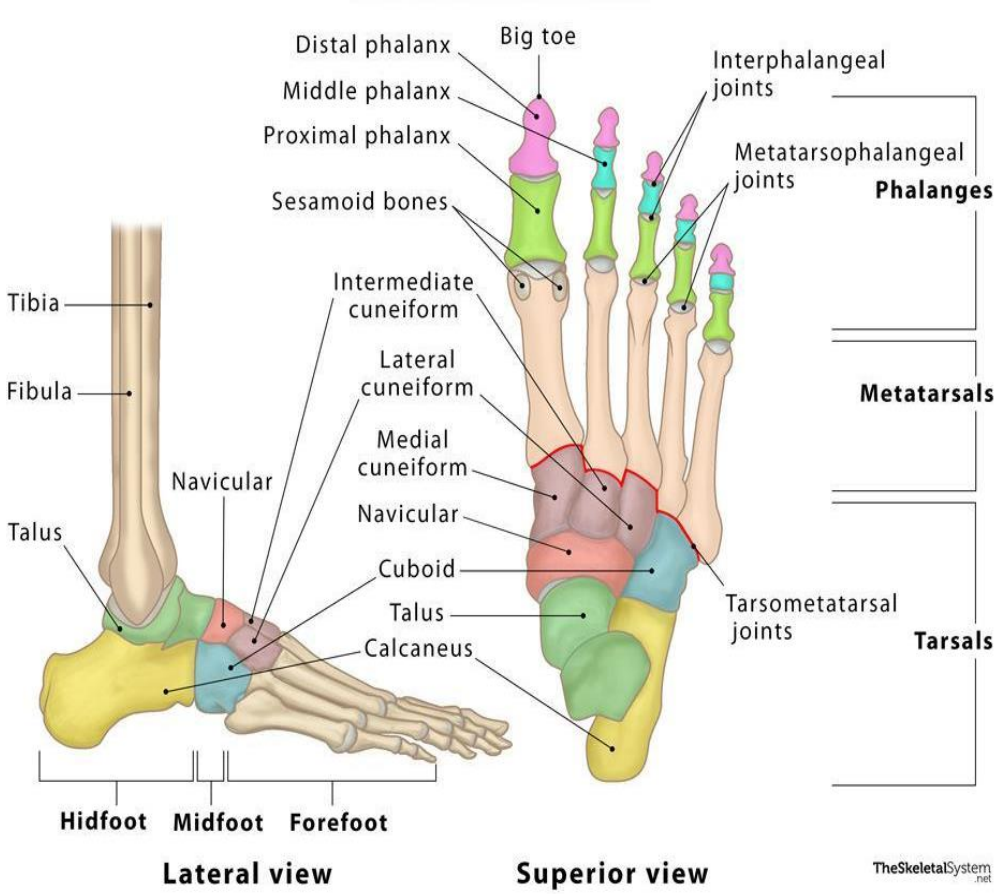

Fig. 2 Distribution of Bones
(Source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.theskeletalsystem.net%2Ffoot-bones&psig=AOvVaw13_Vt5xcf86CC75GxUhI4I&ust=1693065633528000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCMD13o-X-IADFQAAAAAdAAAAABAO)

4. Foot Deformities

Deformities can be painful and affect the way you walk. It may cause a lot of skin to become hard and thick, and lead to calluses and pressure sores. Sometimes misalignments (wrong bone positions) can cause toes and other parts of the foot to become deformed too. This applies abnormal strain on tendons and muscles, which may even tear as a result [25]. Abnormal strain on joints can lead to wear-and-tear, and eventually to osteoarthritis. Further risk factors include injuries, inflammations and being overweight, as well as diseases such as osteoarthritis, rheumatoid arthritis, or brain diseases. Genes usually play an important role. For instance, some people have weak connective tissue, so the supporting structures in the foot cannot always hold everything in place properly. [26]

4.1 Various foot Deformities

a) Hammer toe

Hammer toe is a kind of deformity in which your toe tends to bend or curl downwards instead of pointing forward as shown in fig. 3. It generally affects the second, third, and fourth toe. Although, it may be present at birth and develop over some time due to arthritis or wearing some ill-fitting shoes, such as tight, pointed heels. In most of the cases, a hammer toe condition is treatable. [27]

Fig.3 Hammer toe deformity
(Source: https://www.google.com/imgres?imgurl=https%3A%2F%2Fwww.spineorthocenter.com%2Fwp-content%2Fuploads%2F2020%2F08%2Fhammertoe.jpg&imgrefurl=https%3A%2F%2Fwww.spineorthocenter.com%2Fservices%2Ffoot-ankle%2Fhammertoe-surgery%2F&tbnid=a5TGR903cKgBTM&vet=12ahUKEwjNgK2P6439AhV02nMBHcPxDrQQMygUegUIARCOAg..i&docid=JOVqcB15QZYTeM&w=528&h=400&q=hammer%20toe&ved=2ahUKEwjNgK2P6439AhV02nMBHcPxDrQQMygUegUIARCOAg)

b) Bunion

A bunion also called hallux valgus is a type of foot deformity occurs at first metatarsal phalangeal joint as shown in fig. 4. In this, the big toe generally bends towards the other toes and the joint also becomes red and sometimes painful. The exact cause is still unclear. Some proposed factors include wearing overly tight shoes, high-heeled shoes, family history, and rheumatoid arthritis. Diagnosis is generally based on symptoms and supported by X-rays. [28-30]

Fig. 4 Bunion foot deformity
(Source: https://www.google.com/imgres?imgurl=https%3A%2F%2Fwww.orthoinfo.org%2Fcontentassets%2F4767ec8351ec40639dd4796175ae5847%2Fa00795f01_bunion-2-feet-2_haddad-compressor.jpg&imgrefurl=https%3A%2F%2Forthoinfo.aaos.org%2Fen%2Fdiseases--conditions%2Fbunions%2F&tbnid=PNVwCDsL_y2J-M&vet=12ahUKEwiBpJ_D6439AhXKzHMBHfqRDO4QMygBegUIARDoAQ..i&docid=x5vfrfqnprlFKM&w=2144&h=1424&q=bunion&ved=2ahUKEwiBpJ_D6439AhXKzHMBHfqRDO4QMygBegUIARDoAQ)

c) Splayfoot

In splayfoot deformity, the metatarsal bones are spread out as shown in fig. 5 and the front end of the foot becomes wider. As a result, more pressure is put on the middle bones in the forefoot. It is generally painful, and can make the skin hard and thick, leading to calluses. People with splayfeet are also more likely to develop hallux valgus. In this, the first metatarsal bone moves sideways (towards the other foot) and the big toe moving towards the neighbouring toes [11, 25]

Fig. 5 Splay foot deformity
(Source: https://www.google.com/imgres?imgurl=https%3A%2F%2Fm.psecn.photoshelter.com%2Fimg-get%2FI0000ic1H.xRiUE8%2Fs%2F1200%2FI0000ic1H.xRiUE8.jpg&imgrefurl=https%3A%2F%2Fpeteoxford.photoshelter.com%2Fimage%2FI0000ic1H.xRiUE8&tbnid=DplTO_FB_KlRSM&vet=10CAoQMyhsahcKEwiAnoDp6439AhUAAAAAHQAAAAAQAw..i&docid=U9QAXE1glLeLXM&w=1000&h=664&q=spalay%20foot&ved=0CAoQMyhsahcKEwiAnoDp6439AhUAAAAAHQAAAAAQAw)

d) Fallen arch/ Flat foot

In people with fallen arches, the hollow arch under the foot is flatter than usual as shown in fig. 6. When standing and walking, the foot touches the floor. Fallen arches become painful after several years, mainly when you put more weight on them. Some extreme cases of fallen arches or flat foot are referred to as flat feet. The possible causes of fallen arches include weak foot muscles, abnormal strain on the foot, unsuitable footwear, and some joint inflammations. [11,25]

Fig. 6 Flat foot deformity
(Source: https://www.google.com/imgres?imgurl=https%3A%2F%2Fassets.nhs.uk%2Fnhsuk-cms%2Fimages%2FS_0918_flat_foot_C0220723.max-600x600.jpg&imgrefurl=https%3A%2F%2Fwww.nhs.uk%2Fconditions%2Fflat-feet%2F&tbnid=4P5FRdJHCIJ-fM&vet=12ahUKEwiZhtLN7I39AhXU9nMBHRP-BSwQMygfegUIARCtAg..i&docid=6HirPzQQcEMGFM&w=600&h=400&q=flat%20foot&ved=2ahUKEwiZhtLN7I39AhXU9nMBHRP-BSwQMygfegUIARCtAg)

e) Claw toe

It affects the four smaller toes at a same time. It is bend at the joint as shown in fig. 7 where the foot and the toes meet. It is bend down at the middle joints and at the joints which is nearest to the tip of the toes. As a result, it causes the toes to curl down towards the floor [11, 25, 27].

Fig. 7 Claw toe deformity
(Source: https://www.google.com/imgres?imgurl=https%3A%2F%2Fmedia.sciencephoto.com%2Fc0%2F16%2F69%2F03%2Fc0166903-800px-wm.jpg&imgrefurl=https%3A%2F%2Fwww.sciencephoto.com%2Fmedia%2F520654%2Fview%2Fclaw-foot-in-charcot-marie-tooth-disease&tbnid=OOeM8heH7KlOOM&vet=12ahUKEwja_K2A7Y39AhWkUXwKHZ_UBdcQMygZegUIARCmAg..i&docid=2aFMIOX7QIQx_M&w=800&h=517&q=claw%20foot&ved=2ahUKEwja_K2A7Y39AhWkUXwKHZ_UBdcQMygZegUIARCmAg)

f) Mallet toe

This toe is bend down at the joint as shown in fig. 8 which is closest to the tip of the toe. It affects the second toe, but there is a chance of occurring in the other toes too. [11, 25]

Fig. 8 Mallet toe deformity
(Source: https://www.google.com/imgres?imgurl=http%3A%2F%2Fwww.canyonoaksfootankle.com%2Fwp-content%2Fuploads%2F2020%2F01%2Fdislocated-toe.jpg&imgrefurl=https%3A%2F%2Fwww.canyonoaksfootankle.com%2Fwhat-is-mallet-toe%2F&tbnid=Lioi7ObFO4DQgM&vet=12ahUKEwizoJGn7Y39AhV_jNgFHfNLD_YQMygWegUIARD1AQ..i&docid=Vvn47hPwgks-rM&w=1500&h=1000&q=malletfoot&ved=2ahUKEwizoJGn7Y39AhV_jNgFHfNLD_YQMygWegUIARD1AQ)

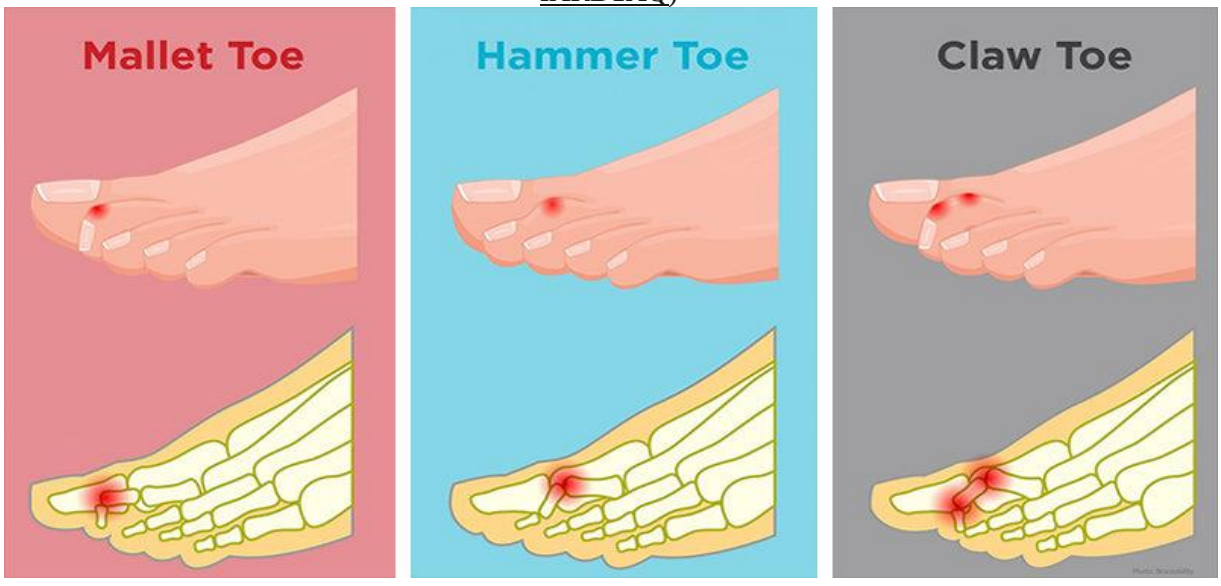

Fig. 9 Comparison of various toe deformities
(Source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.feetfeet.co.uk%2Fblogs%2Fhammer-toes%2Fbent-toes-hammer-claw-mallet&psig=AOvVaw1tTnXPpwplrFgWCN5oX96A&ust=1693066594658000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCMCV_9ma-IADFQAAAAAdAAAAABAE)

g) Cavus Foot

It is a condition in which the child has an excessively high arch as shown in fig. 10. Most of the time, the heel of the foot is turned inwards (called Cavovarus foot deformity). The condition frequently affects both the feet and often progressive. [11, 25-26]

Fig. 10 Cavus foot deformity
(Source: https://www.google.com/imgres?imgurl=https%3A%2F%2Fhealthjade.net%2Fwp-content%2Fuploads%2F2019%2F06%2FPes-cavus.jpg&tbnid=EBXoSUp-fiXNBM&vet=12ahUKEwiAxYH6mviAAxVfmmMGHb6sCyMQMygregUIARDRAQ..i&imgrefurl=https%3A%2F%2Fhealthjade.net%2Fpes-cavus%2F&docid=WwGDf6U9ien1qM&w=1500&h=1180&q=cavus%20foot&ved=2ahUKEwiAxYH6mviAAxVfmmMGHb6sCyMQMygregUIARDRAQ)

5. Research Gaps

1. Most of the researchers tried to increase the distal limit area of toe box for the person who were suffering from different foot deformities. As a result, the shape of footwear affects the aesthetics appeal.
2. Custom made shoes are very costly and its cost depends upon the type of foot deformity.
3. Generally, most of the researchers preferred the natural and synthetic leather for making of custom made shoes. This has its own limitation such as high cost, not good in rain or mud.
4. Individual shoe last is required for a deformed foot, which cannot be reused.
5. Preparation time or lead time for making custom made footwear according to the type of deformity

is more.

6. The custom made footwear is heavy in weight because of the heavy insole and different bottom components like Insole whose weight is depending upon the foot deformities.

6. Problem Statement

To Design and Develop custom made shoe last and low-cost orthopaedic footwear for those who are suffering from different foot deformities

7. Objectives of Studies

1. Study of Anatomy of human foot and its various foot deformities.
2. Design and Development of low-cost custom made shoe last, which may be recycled.
3. Optimization of shoe last.
4. Design and Development of low-cost, light weight custom made footwear.
5. Testing of above customised EVA shoe.

8. Flow chart of the proposed work

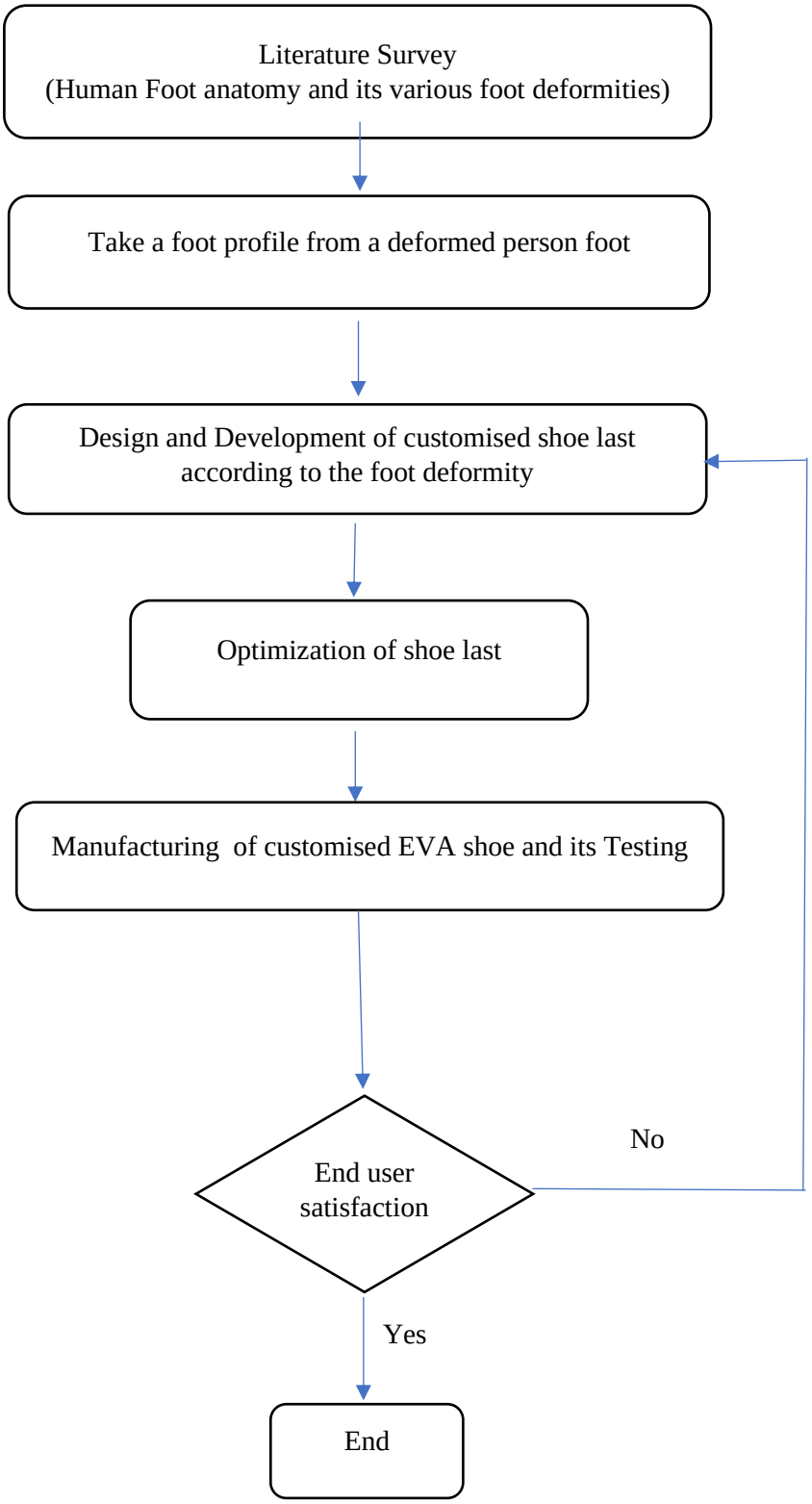
Literature Survey
(Human Foot anatomy and its various foot deformities)
Take a foot profile from a deformed person foot
Design and Development of customised shoe last according to the foot deformity
Optimization of shoe last
Manufacturing of customised EVA shoe and its Testing
End user satisfaction
No
Yes
End

Fig. 11 Flow chart for the proposed work

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